Development of an original lab-scale filtration strategy for the prediction of microfiltration performance: application to fruit juices clarification

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Outlines

Context

Scientific strategy

Results and discussion

Conclusion

Context of the work

Consumption of fruit juices and drinks containing fruit juices

Industrial	Consumer
• Thermal treatments	• Safe product • Fresh-like quality

Cross-flow microfiltration

Membrane permeability decrease

Membrane fouling

Predicting and controlling juice fouling behavior

Context of the work

Most of publications

Optimization approaches and strategies concerning juices microfiltration

Choice of relevant operating conditions, pre-treatment and/or conditioning of juices to be filtered

Lack of knowledge

Prediction of juices microfiltration performance

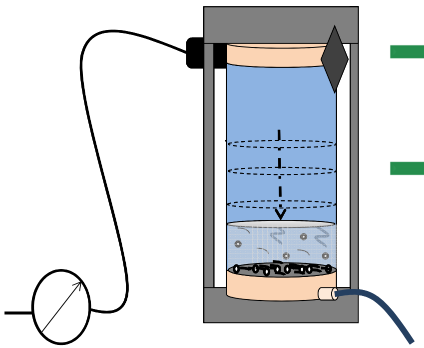
Few adequate prediction tools are proposed to anticipate membrane fouling (Vaillant et al., 2008)

Evaluate fruit juices fouling behavior using conventional filterability tests

Develop a simple and fast prediction tool to anticipate fruit juices fouling behavior

Conventional filterability tests

Dead-end filtration



Pressurized filtration cells

Evaluate the filterability of various suspensions (wine, activated sludge, etc.…)

~~**Ca… ion**~~
~~*Silt density index (SD… odified fouling index (MFI), specific … sistance, etc..*~~
~~(Hong et al., 2009; Alha… et al… 11; Alhadidi et al., 2012)~~

Fouling during fruit juices cross-flow microfiltration is more likely associated to other pore blocking mechanisms
(Machado et al., 2012, de Oliveira et al., 2012)

Scientific strategy

Membrane characteristics

Filterabilty response

Suspension characteristics (fruit juices)

Hydrodynamic conditions

RELEVANT PREDICTION ??

Exploring a broad range of operating conditions in a dead-end filtration cell in order to anticipate orange juice fouling propensity during microfiltration

Scientific strategy

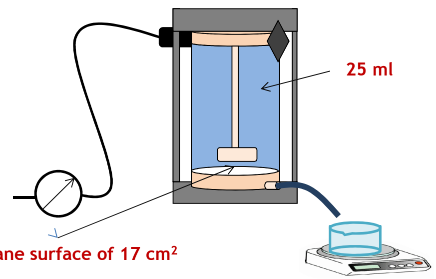
Membrane characteristics

Filterabilty response

Suspension characteristics (fruit juices)

Hydrodynamic conditions

Pressurized and agitated filtration cell



Membrane surface of 17 cm²

Scientific strategy

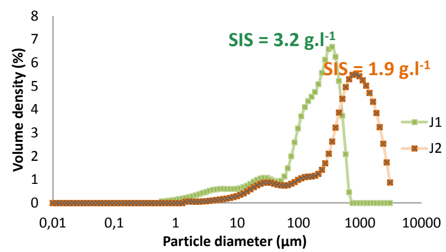
Membrane characteristics

Understand fouling propensity

Suspension characteristics (fruit juices)

Hydrodynamic conditions

Two different orange juices
Commercial pasteurized orange juice (J1)
Fresh squeezed orange juice (J2)
Different physico-chemical characteristics



Scientific strategy

Membrane characteristics

Understand fouling propensity

Suspension characteristics (fruit juices)

Hydrodynamic conditions

Different centrifugation treatments (acceleration-time) to isolate some populations of juice particles

Two different orange juices

3000g-10 min >1 µm

1 nm — 1 µm — 100 µm — 1 mm

Soluble and macromolecules — Colloids — Supra-colloids — Large particles

Scientific strategy

Membrane characteristics

Ceramic (0.2µm)
Glass fiber (1.2µm)

Understand fouling propensity

Suspension characteristics (fruit juices)

Hydrodynamic conditions

Scientific strategy

Membrane characteristics

Understand fouling propensity

Suspension characteristics (fruit juices)

Hydrodynamic conditions

Fixed pressure of 1.5 bar

Different rotational speeds (0, 600, 1200 rpm) ← Shear strain on the membrane wall (0, 500, 1000 s^{-1})

Scientific strategy

Membrane characteristics — 2 levels

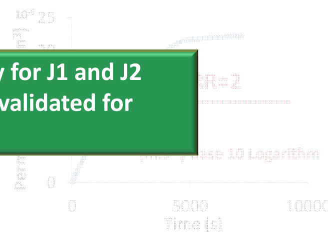
Understand fouling propensity

Suspension characteristics (fruit juices) — 2 juices and 3 levels

Hydrodynamic conditions — 3 levels

D-optimal experimental design (32 experiments)

Variables	Levels		
Membrane	Ceramic (0.2µm)		Glass fiber (1.2µm)
Top-blade stirring (rpm)			
Centrifugation acceleration (g)	0	1500	3000
Centrifugation time (min)	1	5.5	10



The model was analyzed separately for J1 and J2
Both models were significant and validated for prediction (R2>0.93).

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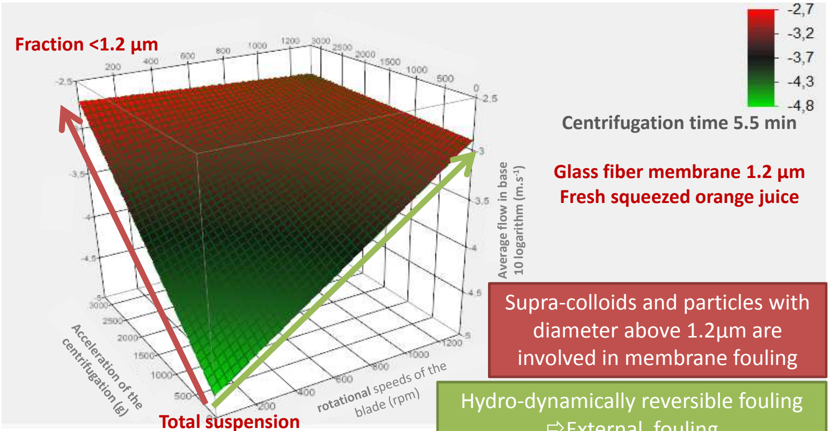
Experimental design results



Centrifugation time 5.5 min

Glass fiber membrane 1.2 µm
Fresh squeezed orange juice

Supra-colloids and particles with diameter above 1.2µm are involved in membrane fouling

Hydro-dynamically reversible fouling
⇨External fouling

Estimation of resistance to filtration R (**Darcy law**)

Resistances in series

In this case : $R_{<1.2\ \mu m} \approx R_{membrane} \rightarrow R_T = R_{>1.2\ \mu m}$

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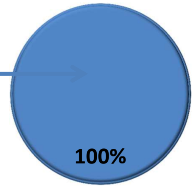
Experimental design results

Based on the same strategy of surface response and resistances in series analysis

supra-colloids and particles **fine colloids aggregates** **colloids and solubles**

External fouling hydro-dynamically reversible



Fiber glass membrane (1.2 µm)

Similar fouling behaviors (J1 and J2)

Supra-colloids and particles (>1.2 µm) were involved in the fouling

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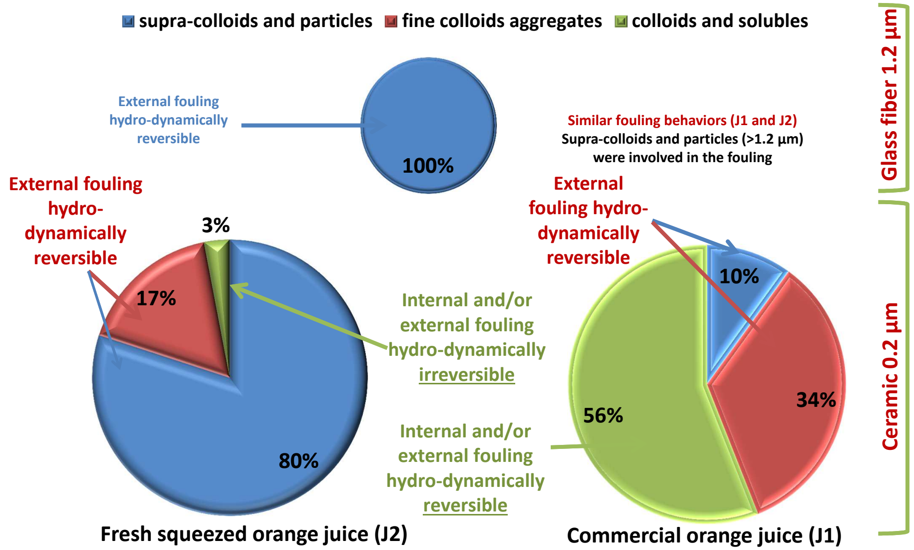
Experimental design results



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Conclusions concerning the experimental design

The experimental design highlighted the important role of the experimental configuration on the response of a filterability test:

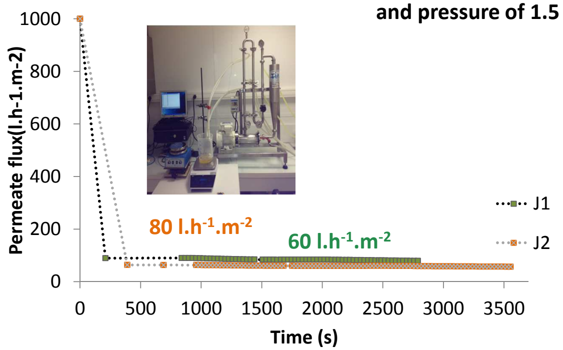
- ✓ **Depending on the membrane used different fouling mechanisms can occur involving different juice components**
- ✓ **Hydrodynamic conditions influence significantly the intensity of the external fouling**
- ✓ **Two different suspensions can present the same fouling behavior but involve different components**

How can this strategy be used to anticipate fruit juices fouling propensity during microfiltration?

Laboratory pilot-scale results

Pilot-scale unit

4 tubular ceramic membranes (0.2 µm), cross-flow velocity of 5m.s^{-1} and pressure of 1.5 bar



According to Hermia's model

Intermediate pore blocking

$$\frac{d^2t}{dV^2} = k.\left(\frac{dt}{dV}\right)^n$$

According to inertial lift

$$R = \sqrt[-3]{\frac{\gamma^2 \rho 0.036}{J \mu}}$$

Only juice compounds with diameter above 1 µm are involved in the fouling mechanisms

Close fouling propensity and fouling behavior of the two juices in the chosen working conditions

Filtration cell results

What will be the operating conditions in the filtration cell giving similar fouling propensities of the two studied juices?

Ceramic membrane 0.2 µm

Centrifugation of 500g during 1 min

stirring of 1000 rpm

Compounds with size lower then 6 µm

Coherent with inertial lift model data

High shear strain

Coherent with crossflow condition

Coherent with working conditions and the observations at pilot-scale

Conclusion

This experimental strategy showed that the conventional dead-end filterability test could be used not only to estimate fruit juices fouling propensity but also to anticipate membrane fouling

- ✓ **Identify the role of the different compounds (particles, supra-colloids, colloids and soluble) of juices on the membrane fouling**
- ✓ **Identify fouling mechanisms (external or internal) and their hydrodynamic reversibility**
- ✓ **Identify suitable operating conditions to anticipate juices fouling propensity**

References

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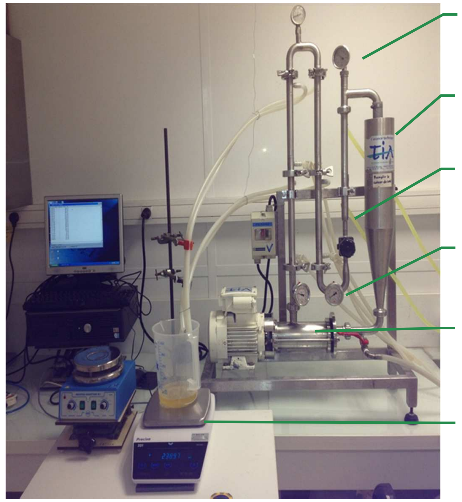
Thank you for your attention

Laboratory pilot-scale description and procedure

The **volume-weight** experimental data were **smoothed** using the Robust Loess algorithm with span of 0.4 (MATLAB®). The smoothed data was numerically **differentiated** and the real-time **permeate flux (J)** was calculated up to a **VRR of 2**



Temperature of 25 ± 2°C

Working volume of 3 Litres

4 Ceramic mono-tubular membrane(0,2µm)

TMP of 1.5 bar

Cross-flow velocity of 5m.s^{-1}

Data acquirement system

Conclusions concerning juices

$$R = \sqrt[-3]{\frac{\gamma^2 \rho 0.036}{J\,\mu}}$$

R=particle radius (m)
Suspension viscosity kg /ms
Wall shear rate